Investigation of the L-Series Lines of Tungsten with a New X-ray Spectrometer (STATES AND STRUCTURE - Atomic and Molecular Physics)

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We have developed a new type of a high resolution X-ray spectrometer. This is a Johann-type crystal spectrometer whose radius of Rowland circle is 750 mm. Moreover, in order to get characteristic X-ray generated by electron excitation, we have made a open-end X-ray tube. With this instrument we observed the L-series lines of tungsten, and measured natural widths. Satellites observed on high energy side of the diagram lines are also examined.

Keywards: Photo diode array/ Coster-Kronig transition/ Wentzel-Druyvesteyn theory

To investigate electron transitions between inner-shells and to have information about atomic configurations, it is very effective to measure X-ray fluorescence spectra. We have developed a new type of a high resolution X-ray spectrometer with which we can observe a X-ray spectrum instantly. The spectrometer is shown in Fig. 1. The radius of Rowland circle is 750 mm. It has three Johann-type crystals, which are Si(111), Si(110), and Si(100). 2θ (θ: Bragg angle) can be changed from about 65 to 95 degrees. The detector is a linear image sensor, a photo diode array (Hamamatsu Photonics S3904-1024Q). Because the path of X-ray is longer than 170 cm, X-ray generated by photo excitation does not have enough intensity to observe a spectrum instantly. Therefore we adopted X-ray by electron excitation as the light source and have made a open-end X-ray tube to get characteristic X-rays of various elements. It is a X-ray tube with a pipe for evacuation. It can be disjointed and a target element in it is remountable. After it is evacuated in the tube about 1×10^{-6} torr, high voltage is applied on the filament. Voltage and current can be applied on the filament up to 50 kV and 50 mA, respectively. The horizontal width of the light source

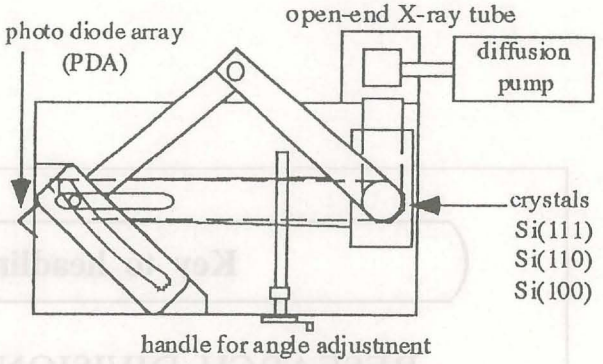

Figure 1. Schematic illustration of a spectrometer.

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STATES AND STRUCTURE —Atomic and Molecular Physics—

Scope of research

In order to obtain fundamental information on the property and the structure of materials, the electronic states of atoms and molecules are investigated in detail using X-ray, SR, ion beam from accelerator and nuclear radiation from radioisotopes. Theoretical analysis of the electronic states and development of new radiation detectors are also performed.

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enabled to have a spectrum because this spectral system is a focusing system. X-ray emitted from different point of the light source enters into a crystal with different angle and focuses on a different channel of PDA. The intensity of X-ray from each point is considered to be equal since the filament length corresponding to energy width of a spectrum is very short. The energy region measured by each crystal is shown in Table 1.

Table 1. Energy region corresponding to each crystal.

Reflection plane	2d (Å)	Energy region (kev)
(111)	6.267	2.7– 3.7
(220)	3.838	4.4– 6.6
(400)	2.714	6.2– 8.5
(333)	2.089	8.0–11.0
(440)	1.919	8.7–12.0

One of applications of this instrument is to study natural widths of characteristic X-rays of various elements. Natural widths of characteristic X-rays or atomic levels have long been investigated experimentally and theoretically. Although there are many reports about K-series lines, there are only a few about L-series lines.Theoretically the energy distribution of the radiation emitted in the electron transition has the lorentzian form of following expression.

$$J(\nu)d\nu=\frac{\Gamma}{2\pi}\frac{d\nu}{(\nu-\nu_0)^2+\left(\frac{\Gamma}{2}\right)^2}$$

where ν is frequency, ν_0 is frequency of the peak, and Γ is the full width at half maximum of the peak. A spectrum observed actually is a convolution of this lorentzian and an instrumental broadening. But an instrumental broadening of this spectrometer is considered to be very small and neglected since each peak can be fitted by only one lorentzian sufficiently. An example of measured spectrum is shown in Fig. 2.

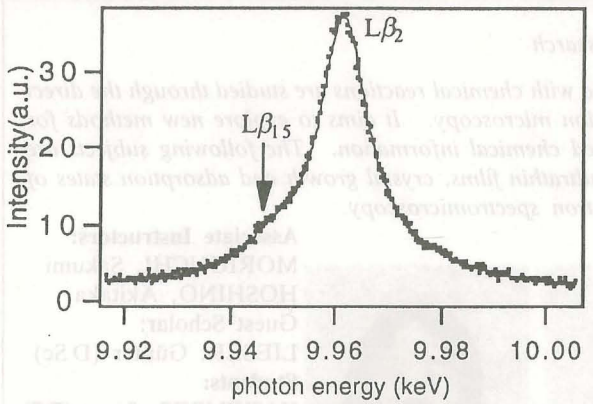

Figure 2. Spectrum of $L\beta_2$ and $L\beta_{15}$ line. Tube voltage is 30 kV, tube current is 15 mA. Crystal is Si(333) and 2θ is 73.13 degrees. Dots are measured value and solid line is fitted by lorentzians.

We show a comparison of the natural widths of L-series lines of tungsten measured in this work and in previous work in Table 2.

Table 2. Natural widths of L-series line of tungsten.

Line	This Work	Ref. 1	Ref. 2	Theory
$L\alpha_1$	7.45	7.16	6.50	5.63
$L\alpha_2$	7.69		7.20	7.90
$L\beta_1$	8.15	7.11	6.90	9.16
$L\beta_2$	10.75	10.1	9.06	12.37
$L\beta_3$	14.32		13.10	16.61
$L\beta_4$	16.85		14.60	17.81
$L\beta_{15}$	11.66			12.54

Theoretical value is derived from calculation of level widths in ref. 3, 4, where we used the fact that the width of characteristic X-ray irradiated by electron transition between two levels is the sum of the widths of each level. There is no drastic difference compared with other measurements, but discrepancy among each value means that more accurate investigations are necessary to be performed on the natural widths of characteristic X-rays.

Observing the spectra, we found some of them have shoulders on high energy side of the diagram lines. These can be explained by Wentzel-Druyvesteyn theory. According to this theory, these are the satellites caused by LX (X=M or N) double holes configuration. For tungsten, such double holes states are created mainly by Coster-Kronig L_1–$L_{2,3}X$ or L_2–$L_{2,3}X$ transitions. So far, we couldn't assign the satellites which correspond to X=N, because the energy shifts of the satellites due to LN double holes are very small. But satellites were observed in the region of energy which correspond to X=M in $L\alpha_1$ and $L\beta_1$ spectra. This fact suggests the existence of Coster-Kronig transition L_1–L_3M as suggested by Salgueiro *et al* [5] in the $L\beta_2$ line, although theoretical calculation of Chen *et al* predicted [6] Coster-Kronig transition L_1–L_3M is energetically forbidden.

The greatest advantage of this instrument is that we can observe phenomena which change time-dependently like chemical reactions. In the future, we will try to observe such phenomena.

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